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Agricultural Processing Wastes: Magnitude of the Problem

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All organic pollution of water and air comes from the photosynthetic reduction of carbon dioxide either through the current growth of crops and forests or from fossil sources, petroleum and coal. In processing agricultural commodities to foods, textiles, leather, and industrial chemicals there are inevitable losses of organic matter, varying from a very small percentage of the amount processed to as much as 25–50% of the raw material entering the plant.

We will consider now the magnitude of these wastes, and discuss certain economic factors, technological factors, and research needs and opportunities.

The losses in organic matter that occur in washing fruits and vegetables, in peeling and cutting them, in cleaning dairy plant tanks and other equipment, in slaughtering meat animals, in manufacturing cornstarch and soy protein, in refining sugar, in scouring wool, in wet processing in textile mills, in liming and tanning hides, constitute a pollutional load that can convert a mountain stream or a river into an anaerobic, stinking mess.

The processing of farm products for food is the principal agricultural processing industry. Almost 18,000 industrial establishments are at present engaged in it.

The paper industry is large, and the size of individual plants makes the problems of stream and air pollution from them especially noticeable.

Cotton and wool processing dominate the textile industry, despite the inroads of synthetic fibers. Leather and soap manufacture, and the production of industrial chemicals from farm products and by-products, comprise another set of important industries which make nonfood products from agricultural materials.

The estimated total pollutional loads from selected industries are presented in Table 1 in alphabetical order. The figures are based on information obtained from articles in the sanitary engineering journals, from the U. S. Public Health Service's Industrial Waste Guides, and from textbooks. Where recent information was unavailable (the fermentation industry and certain miscellaneous industries shown), relatively low estimates have been made. In fact, this table probably underestimates the magnitude of the actual situation, for the sources of the data would be expected to make conservative estimates. Also, certain industries, such as frozen fruits and vegetables, are not listed becau of lack of information.

The last column in the table expresses the potential loading in population equivalents (PE). One PE is the amount of liquid waste equivalent in strength to the normal sewage contributed by one person. It is based on the 5-day biological oxygen demand (BOD) of the waste as compared with the BOD of sewage. The common value of 0.167 pound of BOD per capita per day is used. The limitations of the long-established BOD test, especially in its application to industrial wastes, are well recognized. Nevertheless, the derived PE values are convenient for comparative purposes and constitute only one of the approximations necessary in assessing the overall magnitude of the problem.

The extent to which these wastes reach streams without prior treatment, and the decrease of pollution achieved by the treatment processes for the wastes that are treated, are two major uncertainties that cannot be resolved factually today. An expensive study, in which the amount and strength of effluents from a reasonable sample of each industry were determined, would be required to establish the facts. The

Federal Water Pollution Control Administration, working with the industries, is embarking on this task.

Specific comments on various industries, using the data available, will serve as explanatory notes.

PROCESSING INDUSTRIES

Cannery Wastes

Here the production from the 1963 pack is presented in terms of millions of cases, 24 no. 2½ cans per case (U. S. Department of Agriculture, 1965). Canning wastes consist of washing water from the raw fruits and vegetables, from the cutting and peeling rooms and the cooking sections, and the floor washings. The four products listed in the table are the best-selling consumer items. An estimate of the total wastes from the canning industry is also given. These wastes contain relatively large amounts of solids, most of which can be screened out or precipitated chemically (Industrial Waste Guide—Fruit Processing Industry, 1962; and Besselievre, 1952). The National Canners Association estimates its annual pack at more than 700 million cases and its annual BOD load at 500 million pounds, most of which is treated (Walter Mercer, personal communication, 1966).

Frozen fruit and vegetable packing probably has wastes comparable to canning on a per-pound basis, for the major sources of processing waste are similar.

Corn Wet Milling

The corn wet milling industry, and the similar processing of sorghum for starch, are concentrated in large plants. The organic wastes from this industry are therefore a major problem to the individual company and the community in which it is located. Foley et al. (1955) reported on the industry and an aerobic oxidation process for the treatment of the wastes. The wet milling of corn can be modernized into a "bottled-up" system which recovers and utilizes the various components of corn, wasting a minimum of solids (Foley et al., 1955). This industry has grown in recent years, and problems of stream and air pollution may have become greater.

Table 1. Estimated pollution loadings of selected agricultural processing industries

Processing industry	Annual production, million pounds	5-day BOD: Data in literature	5-day BOD: Pounds BOD per 1000 lb processed	5-day BOD: Potential daily load, 1000 lb	Potential daily population equivalent, millions
Canneries					
Apples	1,218	32 gal 3600 ppm BOD per case of 24 no. $2\frac{1}{2}$ cans	13.3	44	0.26
Peaches	2,970	50 gal 2000 ppm BOD per case of 24 no. $2\frac{1}{2}$ cans	20.8	169	1.02
Corn	2,364	19.5 lb BOD per ton corn processed	9.8	63	0.38
Tomatoes	9,790	8.4 lb BOD per ton tomatoes processed	4.2	113	0.68
Canning, total	...	...	...	1,370	8
Corn wet milling	10,800	1 bu = 1–2 PE	4.5	133	0.80
Cotton, processed through basic dyeing step	4,600	PE (per 1000 lb goods): Sizing 2; Desizing 96; Kiering 108; Bleaching 17; Scouring 12; Mercerizing 83; Basic dyeing 90	68	857	5.14
Dairy		Pounds BOD per 10,000 lb milk equivalent			
Fluid milk	59,000	10	1.0	162	1.0
Evaporated milk	1,888	10.5	2.25	11.6	0.07
Nonfat dry milk	2,176	25.0	26.4	157	0.95
Cheddar cheese	1,157	24.5	23.6	77.6	0.47
Cheddar whey, dried	20% of total	17.0	25.0	9.7	0.06

Cheddar whey	50% of total	350	. . .	500	3.0
Cottage cheese	1,424	350	16.5	64.5	0.38
Cottage cheese whey	7,500	350	. . .	1,000	6.0
Hides and leather	1,300	650 gal 1500 ppm per 100 lb hides	81	300	0.18
Meat					
Slaughtering and packing	59,400	14 lb BOD per 1000 lb live weight	14.0	2,300	13.0
Paper and pulp					
Wood pulp	66,000	300 lb BOD per ton of pulp	150.0	27,000	162
Paper and paper board	96,600	68 lb BOD per ton of paper	34.0	9,000	54
Potatoes					
Chips	2600 ~~7.1~~	29.3 lb BOD per ton raw potatoes	14.6	106	0.64
Dehydrated	1000 ~~2.7~~	71.1 lb BOD per ton raw potatoes	35.6	93	0.58
Flour and starch	1200 ~~3.2~~	57.0 lb BOD per ton raw potatoes	28.5	91	0.55
Frozen French fries	2000 ~~5.4~~	22.0 lb BOD per ton raw potatoes	11.0	57	0.34
Poultry	8,200	33 lb BOD per 1000 birds	10.0	225	1.3
Soybean	300	1.7 lb BOD per 1000 bu	0.19	0.16	0.085
Sugar refining					
Cane	48,000	5.31 lb BOD per ton	Av. 3.0	800	4.8
Beet	47,000	6.64 lb BOD per ton			
Wool scouring	130	8 gal 4000 ppm per lb wool	267	100	0.6

Cotton Textiles

The textile mills constitute another and different stream pollution problem. Cotton manufacture into fabrics has many steps which produce soluble organic wastes, primarily carbohydrates, that contribute to the load of available organic matter in the effluent (Industrial Waste Guide—Cotton Textile Industry, 1959). The use of sizing agents that are less rapidly oxidized by the microflora of the streams has increased in recent years. However, it is difficult to outsmart nature and the ecological situation; therefore, the total load of carbon-containing compounds discharged to a watercourse is the most reasonable measure of the pollutional effect of the textile industry. Since blends of cotton with synthetic fibers are common today, the contribution of cotton alone is not a true measure of the pollution from textile plants.

Dairy Products

The dairy industry, producing milk, cheese, butter, dry skim milk, and other important food products such as evaporated milk, is one of the major food industries. In recent years, cottage cheese consumption has risen greatly, and this section of the dairy processing industry has become a large factor in the industry's waste disposal problems.

Listed here are the annual outputs of four major dairy products, the BOD factors (Industrial Waste Guide—Milk Processing Industry, 1959) used in estimating the wastes from the processing, and the population equivalents of the wastes. This compilation shows that the potential wastes that can accumulate from the receiving and bottling operations in handling whole milk are equal in strength to the daily wastes of a million people. How much of this is treated? We have no good figures, but less than 50% is a reasonable guess.

Whey from the manufacture of Cheddar cheese is a major by-product and waste disposal problem. Groves and Graf (1965) reported that almost 7 billion pounds are produced in Wisconsin annually. About 17% of it is processed directly into dry whey powder. A small amount of the remaining whey is converted into lactose, albumin, and other whey products. Cheese plants situated in areas of high hog production sell, give away, or pay farmers to take whey. More than half of the plants reported that they disposed of all or part of their whey as waste or sewage. Dried whey production capacity has been greater than demand at profitable prices in recent years.

Because of technical difficulties, very little cottage cheese whey has been recovered. A method of drying cottage cheese whey that overcomes these problems has been recently developed and is in limited commercial use (Hanrahan and Webb, 1961).

Hides and Leather

Manufacture of animal skins into leather is the oldest agricultural industry, probably predating the milling of grains. The conversion of skins or hides into leather requires first the removal of the hair, fats, and the soluble proteins and other components of the hide. Tannery wastes contain large amounts of suspended matter including such varied constituents as dirt, dung, blood, fats, lime, hair, and particles of flesh. There are other minor losses of organic wastes in the finishing and dyeing of leather (Rudolfs, 1953; Hubbell, 1955).

Meat Products

The meat processing industries are potential sources of tremendous BOD loadings. Their wastes originate in the slaughtering of animals for food and in the ensuing steps of preparation of animal products for the market. Stockyard wastes contain animal excreta; slaughterhouse wastes contain blood, paunch, manure, flesh, grease, hair, and dirt.

As would be expected, the pollution load contributed by the meat industry is great, amounting to approximately 14 million PE daily. The data cited are from the Industrial Waste Guide—Meat Industry (1954), calculated to production of meat in 1964.

Paper and Pulp

The processing of wood to pulp produces approximately 1000 pounds of dissolved organic matter per ton of pulp. This waste contains large amounts of lignin and about 20% fermentable sugars. These facts, coupled with the great size of the individual plants, make almost obligatory the recovery and use of the by-products to the greatest extent possible. The industry has cooperated in attacking stream pollution. The magnitude of the problem is such that major efforts must be continued, and probably greater costs of waste treatment will have to be paid for by the purchasers of the products. The data cited reflect the relatively slow biochemical oxidation of lignin and cellulose. The BOD values given for pulp manufacture (Copeland, 1964) and for paper (Knowlton, 1964), therefore, are low in relation to the total organic pollution from these industries in its total effect on a river.

The development of forest resources and their utilization in the paper pulp and chemical industries is one of the important trends in the agricultural situation now and in the future, especially in the southeastern states.

Potatoes

In the past decade the potato processing industry has displayed incredible growth. Per capita consumption of fresh potatoes continues to decrease, but per capita consumption of manufactured products is trending upward and adding to the processing waste load. Estimates are presented (Cooley et al., 1964; Pailthorp, 1963) of the wastes from the 1963 production of chips, dehydrated flakes, frozen products, flour, and starch.

The magnitude of the potato processing wastes problem can be illustrated by considering the potato starch industry in Maine (Treadway, 1962). The population equivalent of the effluent from Maine's 28 starch factories is about 950,000 calculated on a total capacity basis (Douglass, 1960). Maine's population (1962 estimate) is 981,000, but only 14 cities have more than 10,000; the PE of the smallest of the 28 factories is two or three times this much. Each of the three largest of the starch factories has a PE approximately that of the state's largest city, Portland, population 72,000.

Poultry

The rapidly expanding poultry processing industry has many types of wastes: offal, bits of flesh, heads, feet, grit, feed, manure, feathers, and grease. Porges and Struzeski (1962) reported on the characteristics of these wastes and processes for their treatment. Recovery of feather meal as a by-product for feed use is a successful commercial operation (Davis et al., 1961).

Soap and Fatty Acids

Despite the rise in synthetic detergents (with their own stream pollution problems) the manufacture of soap, primarily from inedible animal fats, continues to be a major industry. Fatty acids are also produced for many industrial purposes. We were not able to get information from the published literature or from the industry on the magnitude of the pollution problem.

Soybeans

The soybean and its products are utilized for many and varied purposes. After the soybean oil is removed, the resulting meal is used for animal feed, for food products, and for many chemurgic products. Since our figures are based on a plant that instituted rigid control of its wastes (Engelbrecht et al., 1964), they may be well below the industry average. No data are publicly available on the current output of soybean protein products. The value given here (5 million bushels processed) is an informed guess.

Sugar

The liquid wastes produced in sugar refining are highly pollutional. The beet sugar flume water (Kalda, 1958) and the cane wash waters are particularly troublesome (Industrial Waste Guide—Cane Sugar Industry, 1959). Beet sugar manufacture presents especially vexing pollution problems. Production is seasonal, lasting from 60 to 100 days, and is largely concentrated in three states with limited water resources, California, Colorado, and Idaho.

Wool

Wool scouring, both of domestic and imported wool, is one of the long-studied waste treatment problems. The fact that more than 250 pounds of BOD is produced per 1000 pounds of wool processed, as reported in the Industrial Waste Guide—Wool Processing Industry (1955), points up the difficulties. An alternative scouring process developed by the Western Regional Research Laboratory (Fong et al., 1951) has not been adopted by the industry. A later method proposed for decreasing pollution from conventional scouring has been adopted in Europe but not in this country (Fong, 1955).

The liquid wastes from woolen and worsted textile mill processing are probably comparable in magnitude to those from cotton mill processing, on a per-pound basis. However, the much smaller size of the wool industry makes it a less serious source of pollution. Today, many mills process natural and synthetic fibers, and blends of these, so that the problem is often one of the particular textile industry and is not related closely to the various base fibers.

The sum of the PE values of Table 1 is 270 million. As was stated previously, these estimates are conservative for the industries listed, and there are omissions. A reasonable estimate for a total at the present time is 300 million.

For comparison, data prepared for the U. S. Senate Committee on Public Works in 1963 are plotted in Figure 1 (U. S. Senate, Staff Re-

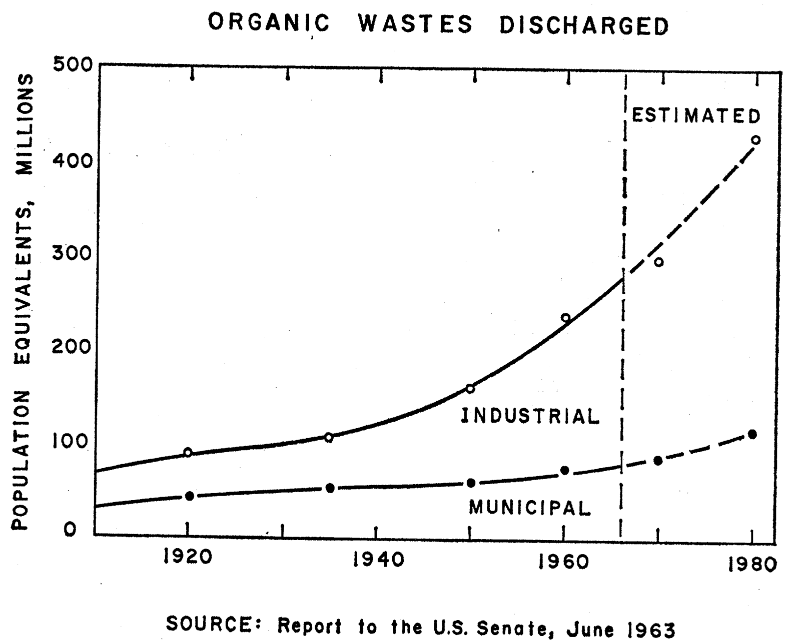

Figure 1. Wastes—magnitude of the problem.

port, 1963). It is not directly comparable to our summation, for in the Senate Report the estimates are of the treated and untreated organic industrial wastes *reaching the watercourses,* and of municipal sewage. In the last 60 years industrial pollution has increased tenfold, and municipal sewage discharge has risen threefold.

By 1980, at the present level of waste treatment, organic waste effluents may make up 75% of the total discharged BOD.

Although the results of our analysis and the Senate Report cannot be directly correlated for the reasons just stated, they are consistent in magnitude.

It must be emphasized that the magnitude alone does not define the problem. There are major differences in the necessary approach to treatment of agricultural processing wastes and sewage treatment. For example, dairy plant wastes contain about 0.1% milk solids (1000 ppm) from normal operation and cleaning of equipment. As these proteins and carbohydrates are readily oxidized by microorganisms, an aerobic oxidizing system must supply oxygen at a rate sufficient to maintain an oxidative environment. Otherwise the system will become anaerobic, and the microorganisms will obtain energy by anaerobic processes, releasing ammonia, various amines, phenols, etc., into the water and the air.

The greater part of the organic compounds in sewage, on the other hand, have already been attacked by microorganisms in the intestines, and are relatively refractory to further oxidation. Moreover, they are quite dilute; a reasonable concentration of dissolved organic solids in sewage is 200–300 ppm.

For these reasons, a plant designed solely for aerobic treatment of sewage cannot handle any appreciable amount of the readily oxidizable, more concentrated wastes that come from the agricultural industries.

It is also apparent that treatment plants designed for combined industrial and municipal wastes must have the needed oxidative capacity built into them. An alternative is to provide an oxidative treatment for industrial wastes and then permit the wastes from this plant to go to a municipal plant. The combination has some advantages, but it requires two separate treatment systems.

Economic Factors

A discussion of economic factors in pollution control usually begins or ends with a statement on how it should be paid for, which reflects the thinking of the industry or regulatory agency the speaker represents. Such considerations are not a part of the present paper.

There *are* important economic factors, however, that are not always clearly brought out in such discussions. Perhaps it will be useful if we call a spade a shovel. First, it has often been said that "the cost of waste treatment is a part of the cost of production." This statement is true only if regulatory agencies make it so. It would be very difficult for the management of any company to go before its board of directors or stockholders with a financial report that included major additional costs for waste treatment above those needed to meet requirements of control agencies.

Second, it must be realized that the cost of waste treatment must be borne by the public. It can be paid for either by increased prices of the products in the market or by taxation. If effluent charges are assessed against a company, or if the company is required to build and operate a treatment facility, the only source of funds to pay for this cost is from an increased selling price of its product. If tax incentives are granted, the general public pays the cost. Despite the repeated statements of how much certain industries pay for waste treatment, the fact is they don't pay for it.

A major factor not often emphasized is that, in the rapidly changing food industry, costs for waste treatment must be tied to production. Industry does not want, cannot afford, high capital costs for waste treatment facilities. For example, it would be foolhardy for a poultry processor to invest in an expensive waste treatment facility of low operating costs, one that could be depreciated over a 20-year period. The management has no assurance that it will be operating that plant even 5 years later. Therefore, even appreciably higher operating costs can be borne if capital costs are kept low. The costs then do become a part of production costs.

This line of reasoning can be extended to argue for combined industrial and municipal waste treatment, the processor paying extra charges based on effluent strength and volume. These charges would be an incentive to keep waste to a minimum. They would also save the processor from capitalizing and operating an additional process—waste treatment. The capital costs would be borne by the community and other governmental units, and in part passed on to the manufacturer as long as the plant operated in the community.

Because of the high concentration of readily oxidizable organic matter and the great variability in the rate of production, both daily and seasonally, industrial disposal systems must be able to take shock loads of as much as 10 times the normal loading without spilling untreated wastes into the receiving stream. These factors of high and variable loading distinguish food processing wastes from municipal wastes. They also complicate the combined treatment with municipal sewage, making it inadvisable to dump the effluent of a large processing operation into a small municipal plant.

Waste segregation, the separation and treatment or disposal of various waste streams, is an important factor in reducing pollution from agricultural processing operations. In certain situations it can be done advantageously, especially in diverting very concentrated residual wastes, such as molasses and soap plant residues, from plant sewer lines.

Waste prevention is often stressed by industry committees and industrial waste guides as an important tool in pollution control. If there is continuing support from top management the employees can be made aware of the importance of preventing spills and overflows, and thereby decrease the amount of waste. But, in general, the plant manager who maintains production schedules, has good labor and community relations, and carries out the manifold other duties of his job well is not required by management to pay a great deal of attention to the ıitary engineer from the main office.

Where We Are in Treatment of Agricultural Processing Wastes

Today agricultural processing wastes are treated by aerobic processes in trickling filter and high and low rate activated sludge systems. Anaerobic treatment of meat packing wastes is successful. Disposal by spraying or ditch irrigation on fields and woodland is effective for dairy, fruit, and vegetable processing wastes. In recent years lagoons have been increasingly successful. Some of them are aerated, and a type of balanced aquarium can be established.

The potential for improving processes, so that less waste, or less deleterious wastes, result, is very good. Many steps in processing developed some years ago when not much attention was paid to stream contamination by effluents need to be reexamined and reevaluated. Water reuse or countercurrent use should effect economies of cost and water consumption. Completely new systems are possible; "dry floor" evaporated milk operations illustrate the possibilities.

By-product recovery offers potential value in certain situations. Increasing needs for protein in the future make new research on fermentation of carbohydrates more promising. For example, food and feed yeast can be propagated in whey wasted from cheesemaking (Porges et al., 1951); microbial protein can also be produced from sugar refinery and paper manufacturing wastes. These fermentation processes, however, have their own major waste disposal problems that must be solved.

Research Needs and Opportunities

Future needs for water, and the multiple reuse of water as it goes down a river, will require a very complete removal of organic matter and of nutrients like ammonia, nitrates, phosphates, and potassium salts from treated wastes. The plant nutrients remain to a considerable extent in the effluent from both aerobic and anaerobic processes. These facts indicate clearly that the return of treated or untreated wastes to the soil will have increasing value in decreasing the problems of growth of algae and other plants in streams, rivers, and lakes.

An acre of land with a good crop cover can be considered to have a foot of depth that, if it can be kept in an aerobic oxidative condition, has a great capacity for absorption and microbial utilization of organic matter. Consider an area of 43,560 square feet, or an equivalent o tank of 43,560 cubic foot capacity, roughly a volume of 320,000 gallons. If we assume 6 inches of useful depth we still have more than 150,000 gallons equivalent per acre. This is a cheap, ready-made oxidative system. It has two further advantages: the plant nutrients are taken up by the crop, and additional crop values can be obtained by pasturing or cutting the grasses for forage crops. Crops other than grasses should be considered.

Research on this problem will require a team approach, utilizing ecologists, microbiologists, and soil scientists, rather than a purely engineering attack. By such studies general principles can be developed, but it is doubtful that general solutions can be found. The variables of location, climate, and soils are so great that installations will have to be individually designed, once the principles are established.

One quite new and interesting area of research now under way in the Department of Agriculture has application in the management of water pollution. It is broadly termed remote sensing. Actually, it is the development of images acquired from the air from many parts of the electromagnetic spectrum: ultraviolet, visible, infrared, both reflected and emitted, and microwave, both active and passive. Two bands appear useful to assess water pollution. First, water appears as a false blue color on color infrared film. Subtle changes in the blue have been noted in different bodies of water, and to date we can equate them with silt and O_2 levels. Second, the temperature difference between point source pollution such as an industrial effluent and the water body into which it is being discharged can be detected by means of a scanner sensitive to the long-wavelength emissive infrared bands. Because these scanners can recognize extremely small temperature differences, the pollution can be detected long distances downstream and traced to its source. We can thus get an instantaneous record of all effluents discharging to a stream. Both systems are at present designed for aircraft use. Their value in assessing pollution and water quality has had only preliminary study.

In view of the long-range needs for food products of an expanding population, and the necessity of conserving water resources for many uses, two additional research areas must be explored in depth.

The research on "exotic" methods of treating sewage and wastes should put a stronger emphasis on industrial wastes. This suggestion is not made with the idea that studies on municipal wastes should be curtailed. Indeed, they should be strengthened by greater emphasis on the microbiological and ecological factors involved. However, if the treatment of industrial wastes is a process that is paid for by the general public in one way or another, as has previously been stated, a long-range program, supported by public funds, on entirely new systems should be instituted.

Furthermore, from the large program on desalination of water, much information will come that can be applied to industrial wastes. It cannot be applied directly, and the job is not the responsibility of those in charge of the desalination research and development program. But it seems inescapable that results will come from studies on this related problem that will lead to new and unique approaches to the treatment of agricultural processing wastes.

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